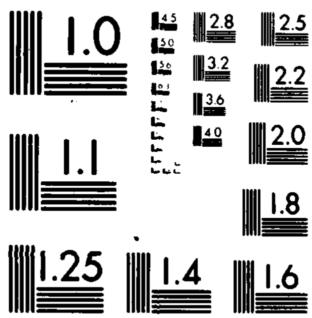

MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS 1963 A

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6 RELIABILITY PREDICTION

FOR

POWER CONTROLLER - DC, LOAD SWITCHING.

11 14 MAR[redacted]80

15 CONTRACT NO N62269-77-C-0413

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FOREWORD

This Reliability Prediction update is submitted as required under Contract N62269-77-C-0413. It is identified as Item A003 in the Contract Data Requirements List (DD 1423) and is part of Contract Line Item 0005AA. The content and format of this plan comply with the requirements of Data Item Description DI-R-2117 and Work Statement Paragraph 9.3.

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D.C. Controller Reliability Analysis and MTBF Prediction

This analysis fulfills the requirements of CDRL Sequence No. A003, Reliability Prediction Report. It has been conducted in accordance with Task R2, Reliability Analysis and Prediction, of the D.C. Power Controller Reliability Program Plan, 15 October 1977.

1.0 DESIGN BASIS FOR PREDICTION

A fourth and final MTBF prediction has been performed for the D.C. Controller; it updates the third MTBF prediction of 23 June 1978. This prediction is based on the D.C. Controller design as of 21 January 1980. This design shows a net increase of two transistors and two capacitors.

2.0 RELIABILITY MODEL AND PREDICTION METHOD

The D.C. Controller is a microelectronics hybrid device. The hybrid failure rate prediction model and procedure of Notice 2 to MIL-HDBK-217B, Reliability Prediction of Electronic Equipment, Section 2.1.7, was employed. This prediction method requires identification of individual electronic parts and substrates, and individual electrical stress data for each part. Thermal stress is caused by the hybrid package temperature and part power dissipation.

3.0 DESIGN DATA SOURCES

The failure rate (F.R.) and MTBF prediction is based on design information updating which has occurred after 1 July 1978. The identification of parts came from design engineering. Parts stress data were obtained from analysis of the updated circuit schematic drawings, January 1980. Additional data on parts and data on substrates were gotten from the circuit and hybrid designers. Integrated circuit and discrete semiconductor information was obtained from manufacturers' handbooks. The substrate areas were taken from the logic/amplifier and power deck (substrates) drawings included in the second design review data package.

4.0 PREDICTION ANALYSIS

4.1 Data Base

The following items summarize the data base for the F.R. prediction:

(a)

Substrates	Dimensions In Inches	Quantity of Film Resistors N_R
Thick film, Power	1.40 x 0.80	16
Thick film, Logic and Amplifier (2 layers)	1.10 x 1.30	44

(b) Active Parts and Capacitors:

There are 51 parts of these categories as detailed in the Failure Rate Summary, Table C. The diodes and transistors are JAN or equivalent quality.

(c) Package:

Cold-rolled steel platform base and top hat soldered lid (bright tin plated) with insulated connection pins extending through the base: perimeter 6.0 inches, height 0.75 inches.

(d) Operating Environment:

Airborne, Uninhabited.

(e) Screening Class (Quality Level) for D.C. Controller: Class B (This is the expected screening level for quantity production).

(f) Hybrid Package Mounting Base Temperature: $25^{o}C$. This is the near-center temperature between the extremes of the operating range: $-54^{o}C$ to $+120^{o}C$.

4.2 Prediction Model and Calculations (Per MIL-HDBK-217B, Notice 2, Section 2.1.7)

The hybrid failure-rate prediction math model is:

$$\lambda_p = [\Sigma N_C \lambda_C \pi_G + (N_R \lambda_R + \Sigma N_I \lambda_I + \lambda_S) \pi_F \pi_E] \pi_Q \pi_D$$

(failures/10^6 hr.)

Where:

$\Sigma N_C \lambda_C \pi_G$ is the sum of the adjusted failure rates for the active components and capacitors in the hybrid from section 2.1.7.1.

N_C is the number of each particular component

λ_C is the component failure rate

π_G is the die correction factor from Table 2.1.7-1.

$N_R \lambda_R$ is the number of (N_R) and failure rate contribution (λ_R) of the chip or substrate resistors (section 2.1.7.2).

$\Sigma N_I \lambda_I$ is the sum of the failure rate contributions of the interconnections (λ_I) FROM SECTION 2.1.7.3.

λ_S is the failure rate contribution of the hybrid package. (Table 2.1.7-4).

π_E is the Environmental Factor for the film resistors, interconnections and package from Table 2.1.7.5.

π_Q is the quality factor from Table 2.1.7-6.

π_D is the density factor from Table 2.1.7-7.

π_F is the circuit function factor
= 1.0 for digital hybrids
= 1.25 for linear or linear-digital combinations

Note: References to Table 2.1.7-X and section 2.1.7.Y are from MIL-HDBK-217B. Tables A through H are in this report.

For the D.C. Controller hybrid:

π_Q = 1.0 From Table 2.1.7-6 (Procured to MIL-M-38510, Appendix G and MIL-STD-883, Method 5004, Class B).

π_D = 1.18 (From Table 2.1.7-7) using the Density calculated as follows:

$$\text{Density} = \frac{\text{No. of Interconnections}}{A_S + .10} \quad \text{where } A_S = \text{substrate area (sq. inches)}$$

Each of two upper substrates: 1.1 in. x 1.3 in. = 1.43 in.^{2}
lower substrate : 0.8 in. x 1.4 in. = 1.12 in.^{2}

Total A_S = 2 x 1.43 + 1.12 = 3.98 in.^{2}

$$\text{Density} = \frac{174 \text{ interconn's}}{(3.98 + 0.10 \text{ in.}^2)} = \frac{174}{4.08} = 42.6 \ \frac{\text{interconnections}}{\text{in.}^2}$$

π_F = 1.25 (ea. of the 3 substrate is a linear-digital combination).

π_E = 3.0 (From Table 2.1.7-5).

λ_S = pkg. F.R. = .0339 f/10^6 hrs. (from Table 2.1.7-4) for Seal perimeter = 6.0 inches and T = pkg. temp. = 25°C.

For the 10 ampere controller (using Tables A and B):

$$(N_N\lambda_R + \Sigma N_I\lambda_I + \lambda_S)\ \pi_F \pi_E = (.0060 + .0303 + .0339)(1.25)(3.0) = .2633 \text{ f}/10^6 \text{ hr.}$$

For the 10 amp. controller:

$$\Sigma N_C \lambda_C \pi_G = 1.1587 \text{ f}/10^6 \text{ hrs. (from Table C).}$$

Using the hybrid model equation and substituting the calculated F.R.'s and π factors:

$$\text{10 amp. Hybrid } \lambda_p = [\,1.1587 + 0.2633\,] \times 1.0 \times 1.18 = 1.6780 \text{ f}/10^6 \text{ hrs.}$$

$$10 \text{ amp. Hybrid MTBF} = \frac{1}{\text{Hybrid } \lambda_p} = \frac{1}{1.678 \times 10^{-6} \text{ failures/hour}} =$$

596,000 hours/failure

For the 5 ampere controller (compared to the 10 ampere controller), two RCA 67654 transistors, two 2N3792 transistors, and 6 substrate film resistors are not needed so that the corresponding failure rates are subtracted from the 10 ampere transistor (Table E) and resistor (Table A) failure rates. The resulting failure rate is 1.5023 failures per 10^6 hours. This corresponds to an MTBF of 666,000 hours.

For the 2 ampere and 1/2 ampere controllers an additional RCA 67654 transistor, a 2N3792 and 4 resistors are not needed (compared to the 5 ampere controller). The resulting failure rate is 1.4160 failures per 10^6 hours. The MTBF is 706,000 hours.

The MTBF's calculated above include the effect on MTBF of the two optocouplers used for trip and fault reporting. Should either of these two devices fail, the controller will still perform its major functions of load on-off switching and tripping open upon overload. If the two optocouplers are removed from the calculations, the following slightly-improved MTBF's result.

10 ampere controller:	601,000 hours
5 ampere controller:	671,000 hours
2 or 1/2 ampere controller:	711,000 hours

4.3 MTBF Objective

The MTBF objective is 1.34×10^6 hours per failure. It appears that this objective is too high for the D.C. Controller, operating in the severe airborne uninhabited environment, becuase it has significant functional capability and complexity, with the consequent hardware complexity. Six IC's, 22 transistors, 9 diodes, 3 optocouplers, 11 capacitors, and 60 resistors are needed to provide the specified functions. The hybrid prediction method of Notice 2 to MIL-HDBK-217B, produces an MTBF about two-to-one lower than the MTBF objective, in spite of the low stresses seen by the parts.

4.4 MIL-HDBK-217C Prediction of MTBF

MIL-HDBK-217C superseded MIL-HDBK-217B in April 1979. With respect to the part types and failure rate models needed for the D.C. Controller predictions, two major changes appear. First, the failure rates of certain discrete semiconductors drop because of a reduction in their Quality Factor multiplier, π_Q. The π_Q's of transistors (Group I) and voltage-regulator diodes (Group V) became 60% of their former values; the π_Q of general-purpose diodes dropped to 30% of its former value. Second, the airborne uninhabited (A_U) environment of MIL-HDBK-217B is supplanted by one of two new environments: airborne uninhabited, transport (or bomber) A_{UT}, or airborne uninhabited, fighter (or interceptor) A_{UF}. The values of

the new environmental factors, π_E, have a 1:2 ratio, and, for most part types, bracket the π_E (A_U) value by a ratio of 1.4:1 on either side. For discrete semiconductors, however, the new π_E's are lower, i.e., π_E for A_{UT} is one half of π_E for A_U, while π_E for A_{UF} is the same as π_E for A_U.

For the 10 ampere hybrid, the combined effect of these two major changes is estimated to produce the following comparative MTBF results:

	Mean Hours Per Failure
MIL-HDBK-217B, Notice 2 (A_U)	600,000
MIL-HDBK-217C (A_{UF})	500,000
MIL-HDBK-217C (A_{UT})	1,000,000

TABLE A

Hybrid Resistor Failure Rate Calculation

(Either Chip or Substrate R's)

(From 2.1.7.2 of MIL-HDBK-217B, Notice 2, 17 March 1978)

N_R = No. of (chip or) substrate R's = 60

λ_R = F.R. of (chip or) substrate R's = .00010 f/10^6 hr. (for T≤50°C) from Table 2.1.7-2 where T is the hybrid pkg. temp.

$\lambda_{\text{hybrid R's}} = N_R\lambda_R$ = 60 x .00010 f/10^6 hrs. = .0060 f/10^6 hrs.

TABLE B

Hybrid Interconnection Failure Rate Calculation

	ITEM QTY.	$N_{I/ITEM}$	QN_I
Ea. IC chip bonding pad	78	1	78
U7 8 bonding pads U1 14 bonding pads U2 14 bonding pads U3 14 bonding pads U5 14 bonding pads U6 14 bonding pads Total 78 bonding pads			
Ea. Transistor	22	2	44
Ea. Diode	8	1	8
Ea. Capacitor	11	2	22
Ea. External Lead	20	1	20
Ea. External Diode	1	2	2

No. of Interconnections $= \Sigma N_I = 174$

at 25°C package temp

$$\lambda_{I_1} = \lambda_{I_2} = .000174\ f/10^6 \text{ hrs. (from Table 2.1.7-3)}$$

hence: $\Sigma N_I \lambda_I = 174 \times .000174\ f/10^6 \text{ hrs.} = .0303\ f/10^6 \text{ hrs.}$

TABLE C

Active Parts and Capacitors Failure Rate Summary

($\Sigma N_C \lambda_C \pi_G$ = Sum of Adjusted λ's for Active Components and Capacitors)

	$N_C \lambda_C \pi_G$ ($\lambda_T \pi_G$)	REFERENCE
6 IC's	.5212 f/10^6 hrs.	TABLE D
22 Transistors	.3743 "	TABLE E
9 Diodes	.0582 "	TABLE F
3 Optocouplers	.0234 "	TABLE G
11 Capacitors	.1816 "	TABLE H
51 Parts	$\Sigma N_C \lambda_C \pi_G$ = 1.1587 f/10^6 hrs.	

TABLE D

INTEGRATED CIRCUITS & FAILURE RATE CALCULATION (T_A = 25°C)

3 CMOS Digital IC's:

	π_L	π_P	Gates	T_j	π_{T2}	C_1	C_2	π_Q	π_E
CD4070B	1.0	1.0	4	30°C	.155	.0033	.0064	2	6
CD4001B	1.0	1.0	4	30°C	.155	.0033	.0064	2	6
CD4011B	1.0	1.0	4	30°C	.155	.0033	.0064	2	6

CMOS IC: $\lambda_p = \pi_L \pi_Q (C_1 \pi_{T2} + C_2 \pi_E) \pi_p$ f/10^6 hrs.

$= 1 \times 2\ (.0033 \times .155 + .0064 \times 6) \times 1$

$= 2\ (.00051 + .0384) \times 1$

$= .0778$ f/10^6 hrs. for ea. CMOS IC

3 Linear Bipolar IC's:

	π_L	π_P	XSTRS	T_j	π_{T2}	C_1	C_2	π_Q	π_E
CA 124	1.0	1.0	52	35°C	.24	.011	.023	2	6
CA 139	1.0	1.0	32	35°C	.24	.0079	.017	2	6
LM 723	1.0	1.0	16	35°C	.24	.0046	.012	2	6

Linear IC: $\lambda_p = \pi_L \pi_Q (C_1 \pi_{T2} + C_2 \pi_E)$

CA 124: $\lambda_p = 1 \times 2\ (.011 \times .24 + .023 \times 6) = .2813$ f/10^6 hrs.

CA 139: $\lambda_p = 1 \times 2\ (.0079 \times .24 + .017 \times 6) = .2078$ f/10^6 hrs.

LM 723: $\lambda_p = 1 \times 2\ (.0046 \times .24 + .012 \times 6) = .1462$ f/10^6 hrs.

λ_T for 6 IC's:
.0778 f/10^6 hrs.
.0778 f/10^6 hrs.
.0778 f/10^6 hrs.
.2813 f/10^6 hrs.
.2078 f/10^6 hrs.
<u>.1462</u> f/10^6 hrs.

λ_T = .8687 f/10^6 hrs. = unadjusted F.R.
x .6 (=π_G) adjustment factor for dies

Adjusted F.R. = $\pi_G \lambda_T$ = .52122 f/10^6 hrs.

TABLE E

Transistor Failure Rate Calculation

$\pi_E\pi_Q = 8$

$\pi_G = .4$ $\pi_E = 40$ $\pi_Q = .2\text{(JANTXV)},\ T_c = 25^oC$

PART TYPE	GRP I	QTY	λ_b	POL-ARITY	S	π_A	π_R	π_{S2}	π_C	RATINGS P(W)	RATINGS V_{CEO}
RCA 67654		4	.0046	NPN	<.1	.7	5.0	.48	1.0	175	80
2N3792		4	.0065	PNP	<.1	.7	5.0	.48	1.0	90	80
2N6316		2	.0046	NPN	.1	1.5	5.0	.30	1.0	90	80
2N5339		1	.0046	NPN	.1	.7	2.0	.36	1.0	6.0	100
2N3019		2	.0046	NPN	.1	1@ .7 1@1.5	1.5	.30	1.0	>1to5	80
2N5550		6	.0046 .0075	NPN	.1 .4	5@ .7 1@1.5	1.0	.30	1.0	1.0	140
2N2484		2	.0046	NPN	.1	1@ .7 1@1.5	1.5	.30	1.0	1.2	60
2N3251		1	.0065	PNP	.1	.7	1.5	.30	1.0	1.2	40

$N\lambda_p$ =	N	λ_b	π_A	π_R	π_{S2}	$\pi_E\pi_Q\pi_C$		$N\lambda_b\pi_A\pi_R\pi_{S2}$
(4) 67654	4 x	.0046 x	.7 x	5.0 x	.48 x	8	= 6.72 x .0111 =	.07459
(4) 2N3792	4 x	.0065 x	.7 x	5.0 x	.48			
(2) 2N6316	2 x	.0046 x	1.5 x	5.0 x	.30			.02070
2N5339	1 x	.0046 x	.7 x	2.0 x	.36			.00232
(1) 2N3019, (1) 2N2484	2 x	.0046 x	.7 x	1.5 x	.30		= 2.2 x .00414 =	.00911
(1) 2N3019, (1) 2N2484	2 x	.0046 x	1.5 x	1.5 x	.30			
2N5550	1 x	.0075 x	1.5 x	1.0 x	.30			.00337
2N3251	1 x	.0065 x	.7 x	1.5 x	.30			.00205
(5) 2N5550	5 x	.0046 x	.7 x	1.0 x	.30			.00483

λ_T for 22 XSTRS= $\Sigma N_i\lambda_{pi}$ = .9358 f/10^6 hrs. = 8 x .11697

$\lambda_T\pi_G$ = .9358 x .4 = .3743 f/10^6 hrs. = adjusted F.R.

TABLE F

Diode Failure Rate Calculation

$T_C = 25^oC$

$\pi_G = .2$ ALL JAN TXV, $\pi_Q = .5$, $\pi_E = 40$, $\pi_C = 1$

Group IV: $\lambda_p = \lambda_b(\pi_E\pi_A\pi_Q\pi_R\pi_{S2}\pi_C)$

PART NO.	TYPE	QTY	S	λ_b	π_A	π_R	π_{S2}	$\pi_E\pi_Q\pi_C$	RATINGS I(A)	RATINGS (PIV)
1N4148	SW'G	3	.1	.0009	0.6	1.0	0.7	20	.2	100
1N4148	SW'G	1	.1	.0009	1.0	1.0	0.7	20	.2	100
1N4002	SW'G	1	.1	.0009	0.6	1.0	0.7	20	1.0	120

Group V: $\lambda_p = \lambda_b(\pi_E\pi_A\pi_Q)$

PART NO.	TYPE	QTY	S	λ_b	π_A	$\pi_E\pi_Q$	P(W)
MCC 3.6A	Zener	1	.1	.0031	1.0	20	.25
MZ 43B10	Zener	1	.1	.0031	1.0	20	.25
1N3040B	Zener	2	.1	.0031	1.0	20	1.0

	N	λ_b	π_A	π_R	π_{S2}	$\pi_E\pi_Q$	π_C	$N\lambda_b\pi_A\pi_R\pi_{S2}$
(3) 1N4148, (1) 1N4002	4	.0009	0.6	1.0	0.7	20	1.0	.001512
(1) 1N4148	1	.0009	1.0	1.0	0.7	20	1.0	20x .000630
(1) MCC 3.6A	1	.0031	1.0			20		.012400
(1) MZ 43B10	1	.0031	1.0			20		.014542
(2) 1N3040B	2	.0031	1.0			20		

λ_T for 9 Diodes $= \Sigma N_i\lambda_{pi} = .2908 = 20 \times .014542$ f/10^6 hrs.

Adj. F.R. $= \lambda_T\pi_G$(diodes) $= .29084 \times .2 = .058168 \approx .0582$ f/10^6 hrs.

TABLE G

Optocoupler Failure Rate Calculation

$\lambda_p = \lambda_b \pi_C \pi_E \pi_Q$ $\pi_G = 1.0$ (packaged in metal cans)

$\pi_E = 6, \pi_Q = 1$

PART NO.	QTY(N)	S	λ_b	π_C	$\pi_E\pi_Q$	$N\lambda_p = N\lambda_b\pi_C\pi_E\pi_Q$
OPI 1991(OPI 140)	2	.1	.0006	1.5	6	0.0108 f/10^6 hrs.
OPI 1991(OPI 140)	1	.3	.0014	1.5	6	0.0126 f/10^6 hrs.

Adjusted F.R. = $\pi_G \lambda_T = \Sigma N_i \lambda_{pi}$ = 0.0234 f/10^6 hrs.

TABLE H

Capacitor Chip Failure Rate Calculation

$T_A = 25^oC$, $\pi_G = 0.8$

H-1 Ceramic 125^oC Rating $\lambda_p = \lambda_b(\pi_E\pi_Q)$ $\pi_E = 10$, $\pi_Q = 1$ (MIL-C-39014, Level M)

λ_b on Table 2.6.4-4 (125^oC Rating)

PART TYPE	VOLTAGE	N QTY	S	λ_b	$\pi_E\pi_Q$	
CKR06 100,000pf	100	2	.1	.0019	10	$N\lambda_p = N\lambda_b\pi_E\pi_Q$
CKR05 10,000pf	100	4	.1	.0019	10	
CKR05 4,700pf	100	1	.1	.0019	10	$N\lambda_p = 10 \times .0190 = .1900$ f/10^6 hrs.
CKR05 1,000pf	200	3	.1	.0019	10	
CKR06 100,000pf	100	1	.3	.0037	10	$N\lambda_p = 1 \times .0037 \times 10 = .0370$

$\lambda_T = \Sigma N_i\lambda_{pi} = .1900 + .0370 = .2270$ f/10^6 hrs.

Adjusted F.R. $= \pi_G\lambda_T = 0.8 \times .2270 = .1816$ f/10^6 hrs.

F

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